Recognition and Reconstruction for Life-Cycle Monitoring and Assessment of Infrastructure

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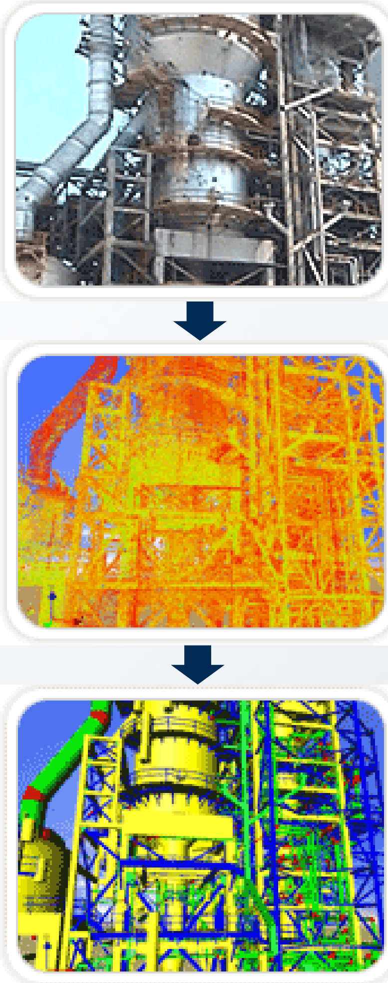
Georgia Institute of Technology®

Introduction

- Restoring and Improving Urban Infrastructure
  - An Engineering Grand Challenge (NAE, 2008)
  - Lack of viable methods to map/label existing infrastructure
    - E.g. 2/3 of effort needed to model simple infrastructure spent on manually converting surface data to a geometric model (Jaselskis et al., 2008)
      - Result: As-built models not produced for most new and retrofit construction
      - Leads to rework and design changes (NAE, 2008)
        - » Cost up to 10% of installed costs (Reddington, 2005)
        - » Lead to reduced sustainability (significant material waste)

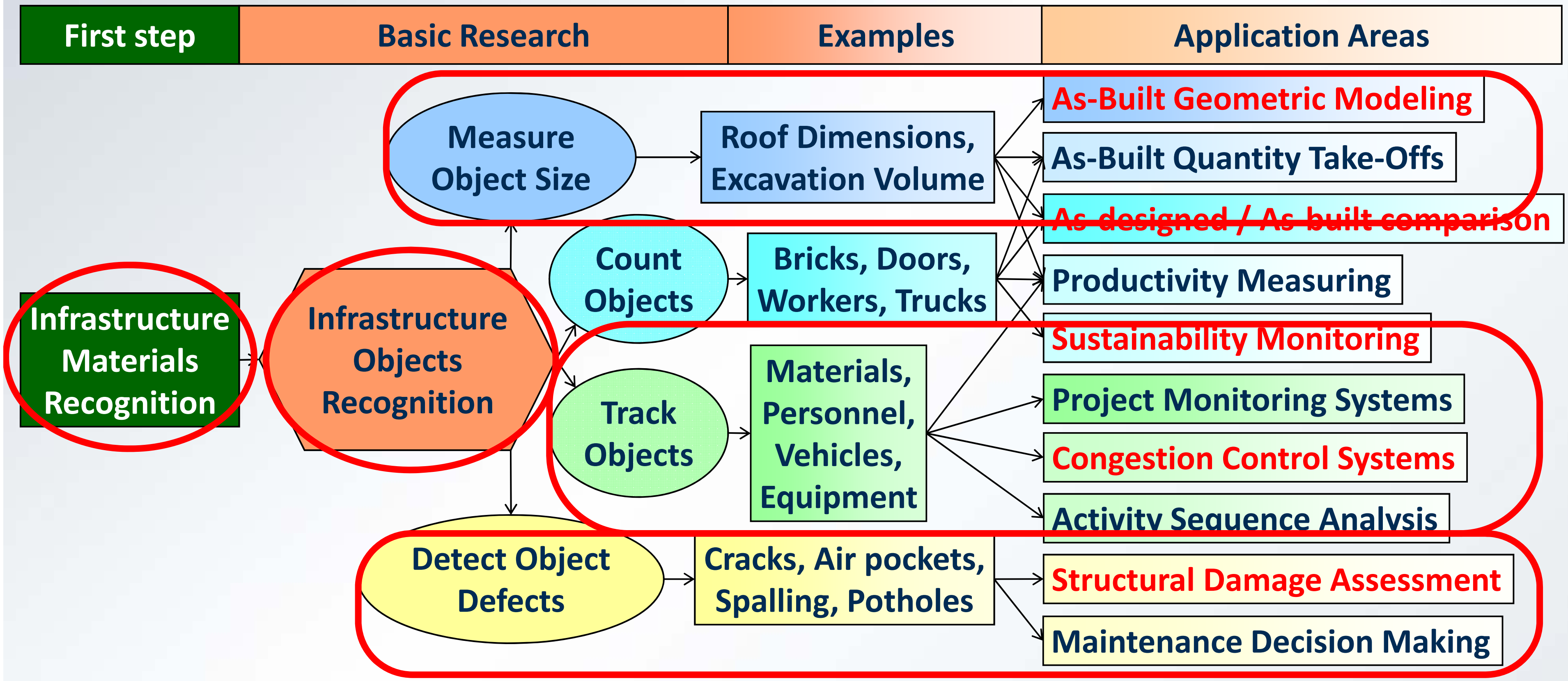


How do you build better infrastructure?

Novel construction materials may help address some of these challenges. But dramatic progress may be possible only by developing entirely new construction methods. Most of the basic methods of manual construction have been around for centuries — even millennia. Advances in computer science and robotics should make more automation possible in construction, for instance, greatly speeding up construction times and lowering costs. Electricity networks linking large central-station and decentralized power sources will also benefit from greater embedded computation.

Outline

CAREER Award #0948415



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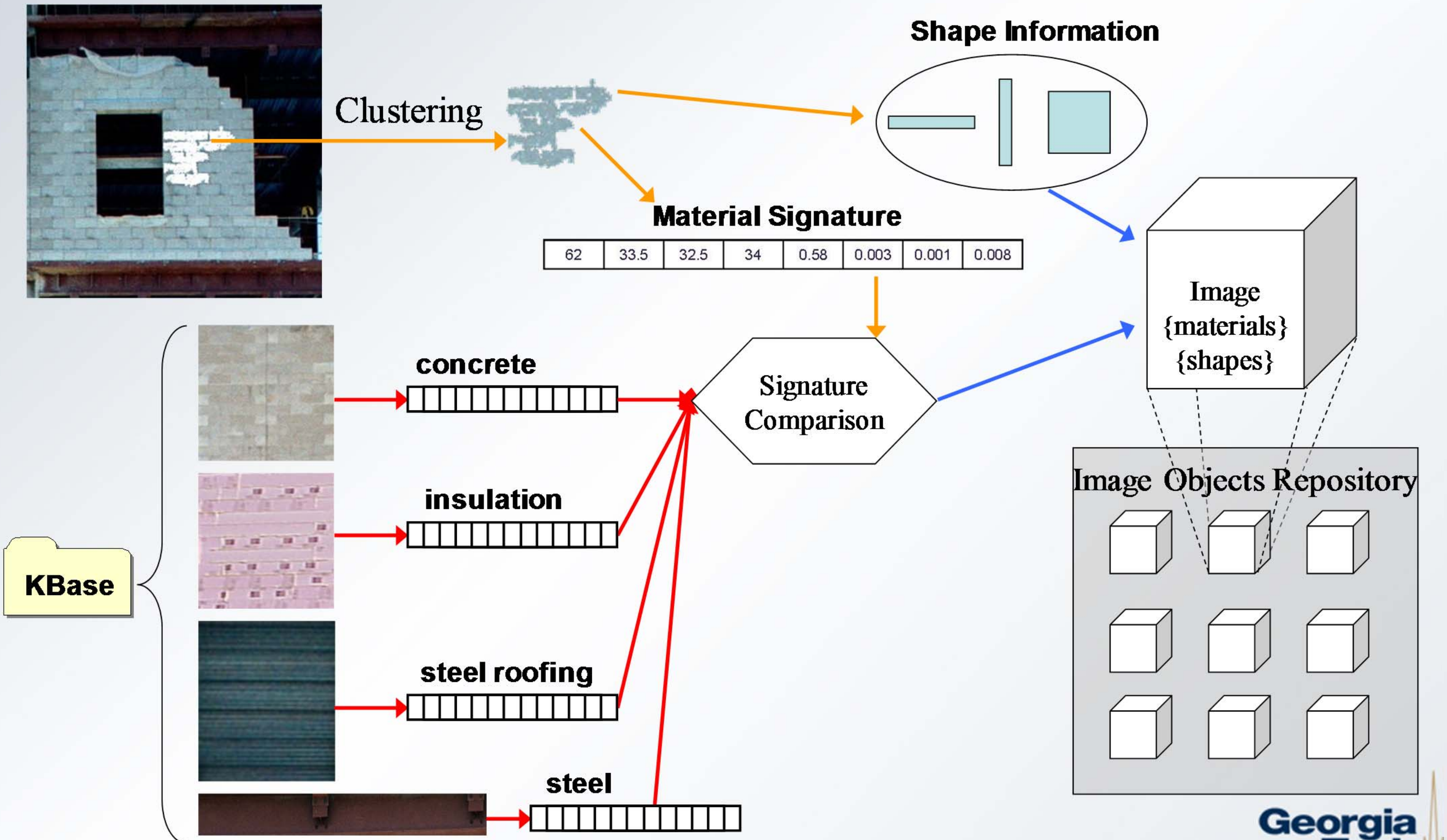
Material Based Image Classification



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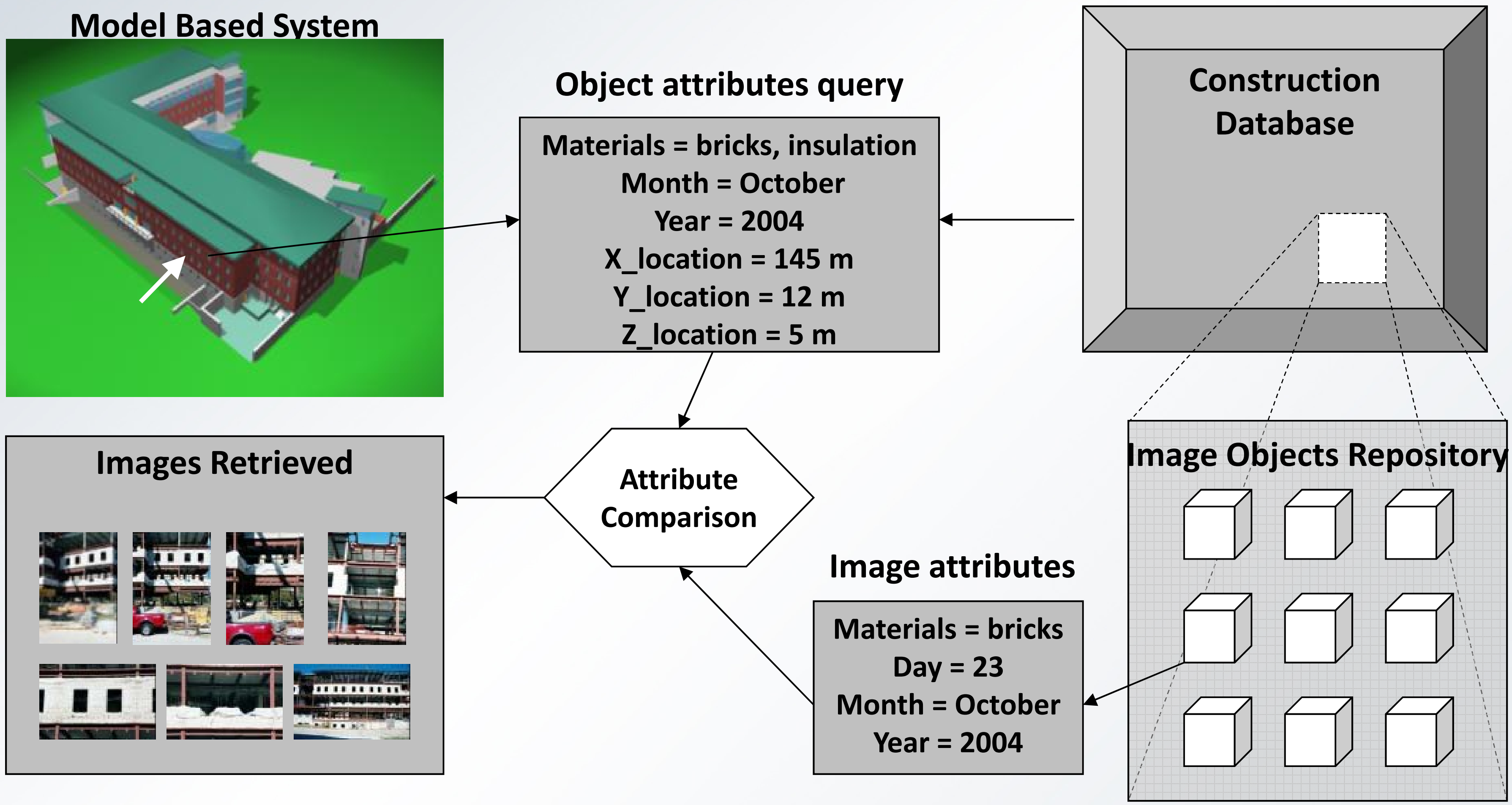
Multi-modal Image Retrieval



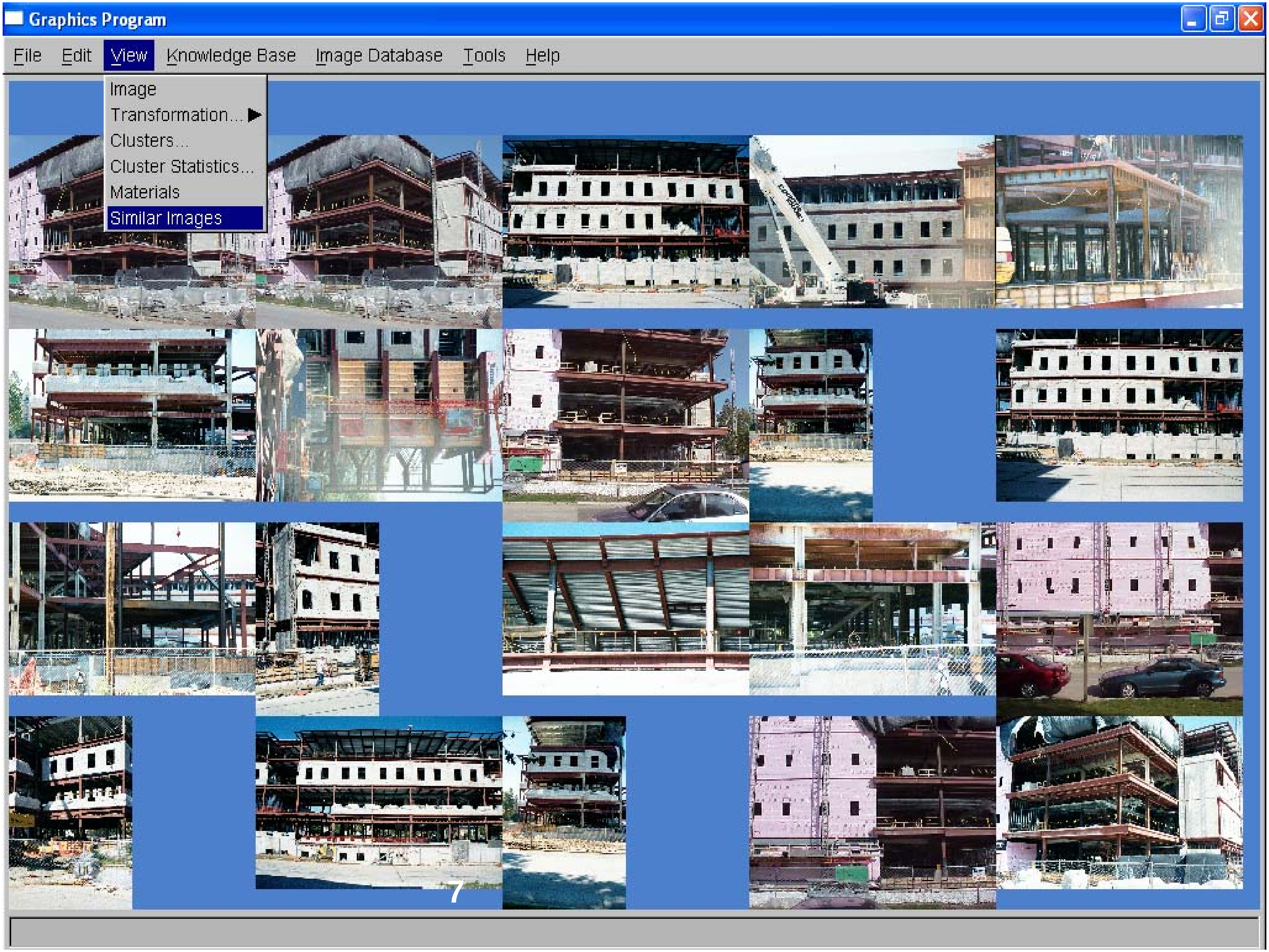

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Image Database
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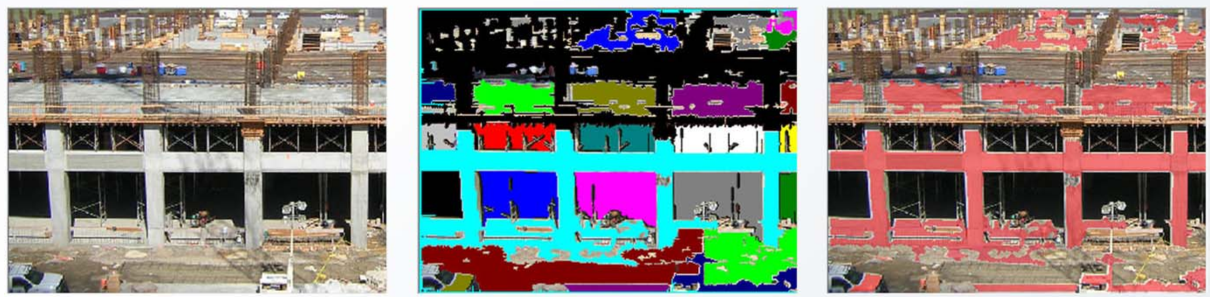
Image
Transformation...
Clusters...
Cluster Statistics...
Materials
Similar Images

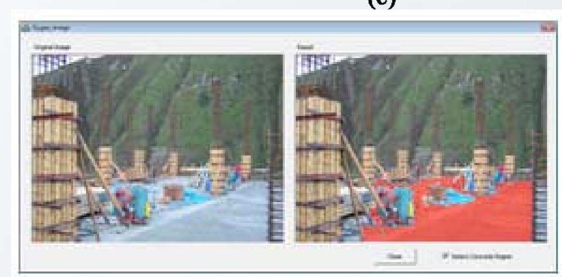
Results

- Avg. Precision [(TP/(TP+FP)] = 85%
- Avg. Recall [TP/(TP+FN)] = 82%
- Avg. Generality [(TP+FN) / (TP+TN+FP+FN)] = 2.5%
- Much better results when using a CCD sensor instead of a CMOS sensor

No.	TP	TN	FP	FN	Precision	Recall	Generality
1	20988	574422	1625	2095	92.8%	90.9%	3.9%
2	8185	482261	1648	2666	83.2%	75.4%	2.2%
3	10172	507891	1447	1047	87.5%	90.7%	2.2%
…	…	…	…	…	…	…	…



(a) (b) (c)



Infrastructure Objects Recognition

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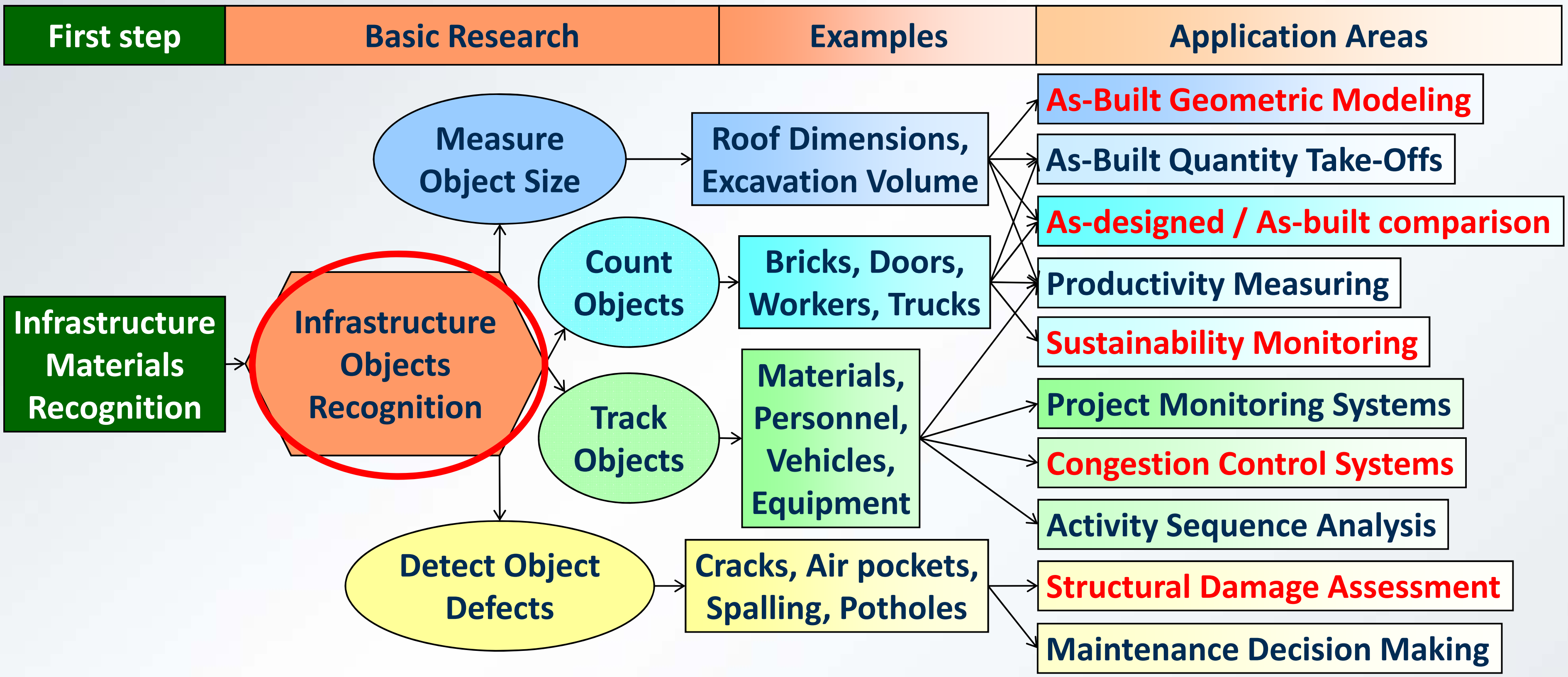

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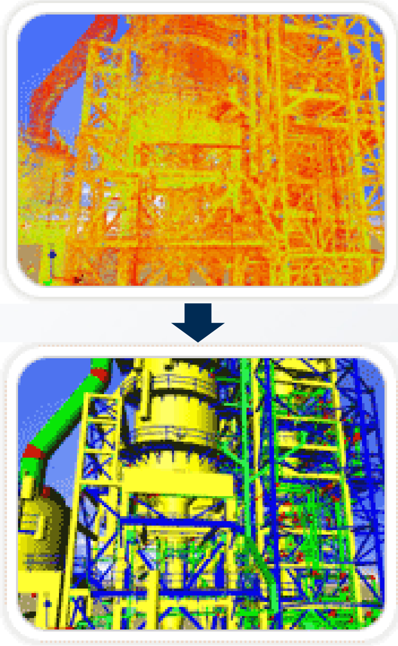
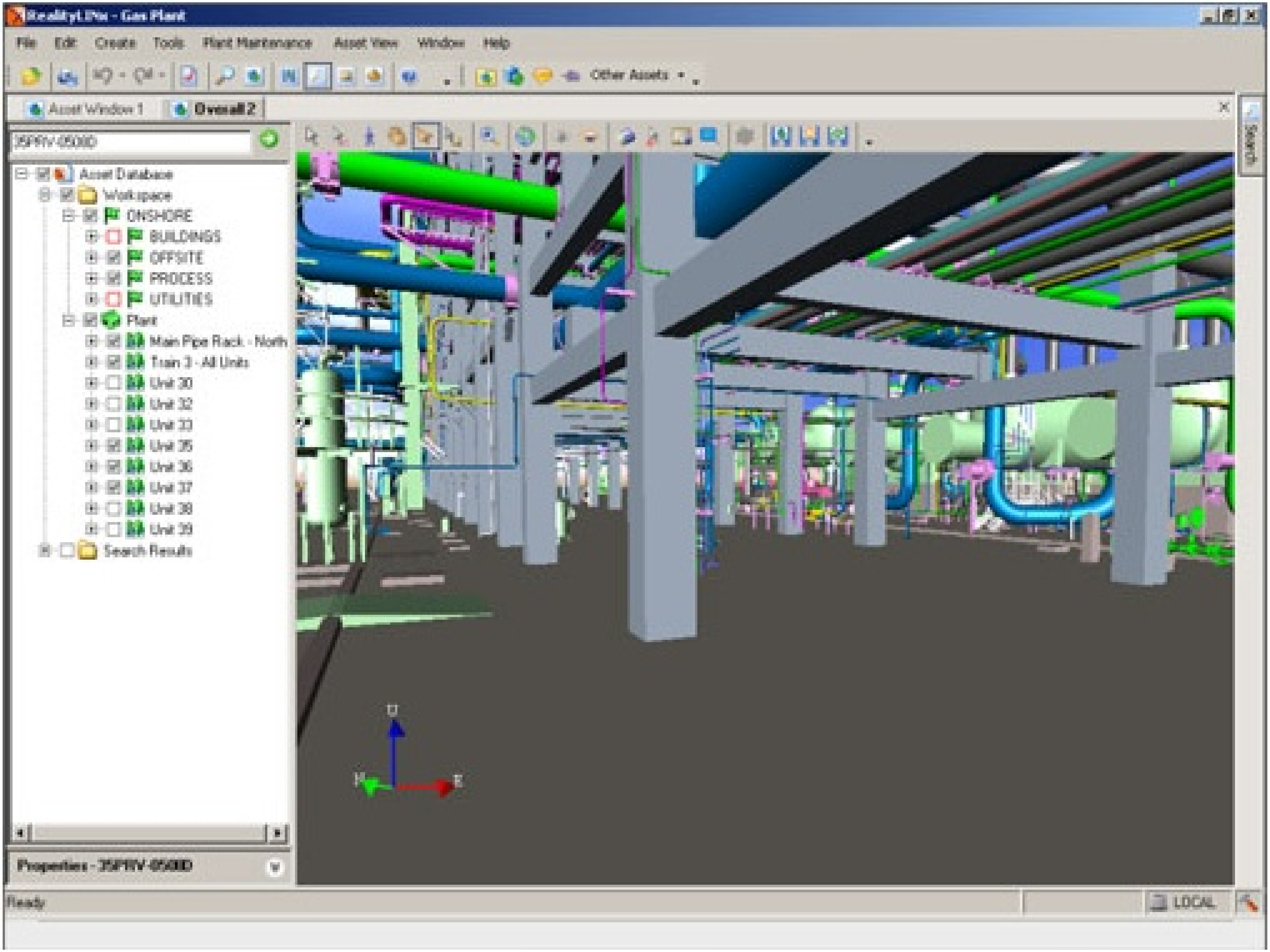
From spatial/visual data to a 3D Model

- Point clouds / images have no knowledge of the elements they contain
  - What they are made of
  - Which points/pixels belong to which entities
- Cannot provide any other as-built information besides spatial measurements
  - i.e. material info, health info, etc.
- Purpose of as-built modeling =
  - Convert spatial/visual data to information rich, object-oriented model




RealityLINx - Gas Plant
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Other Assets
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Overall 2
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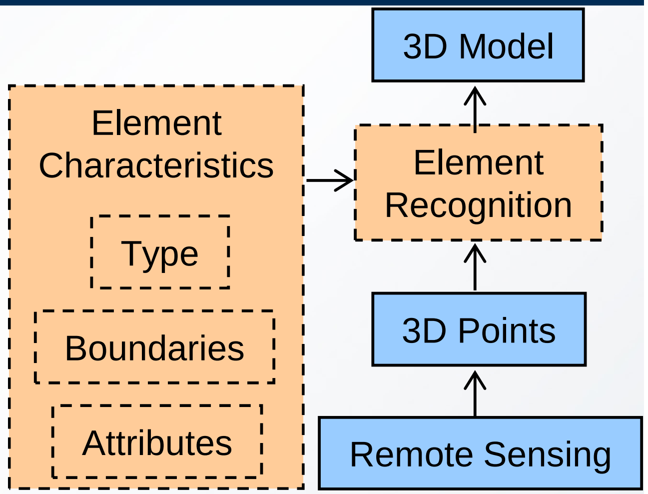
State of Practice

- From 3D points to 3D Objects
  - Processes
    - Recognize each object
    - Match with a template object
    - Addition of non-spatially related attributes
    - Link generated object in 3D model
  - Processes are manual, time-consuming and costly
    - This cost and effort counteracts the benefits of as-built modeling for the majority of infrastructure
  - Research question: How to automate the process?



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Infrastructure Objects Recognition

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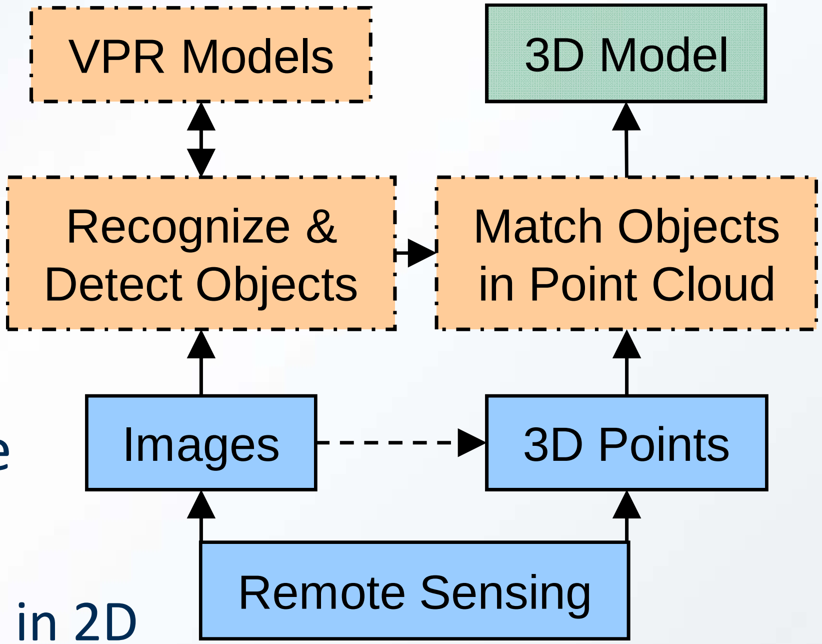
- Proposed Solution
  - Build VPR model repository
    - Gradual
  - In every modeling process
    - Collect visual data of the scene
      - Apply 2D-part of VPR models
      - Recognize and detect objects in 2D
    - Collect or generate spatial data of the scene
      - Apply 3D-part of VPR models
      - Match 2D detected objects in point cloud



Infrastructure Objects Recognition

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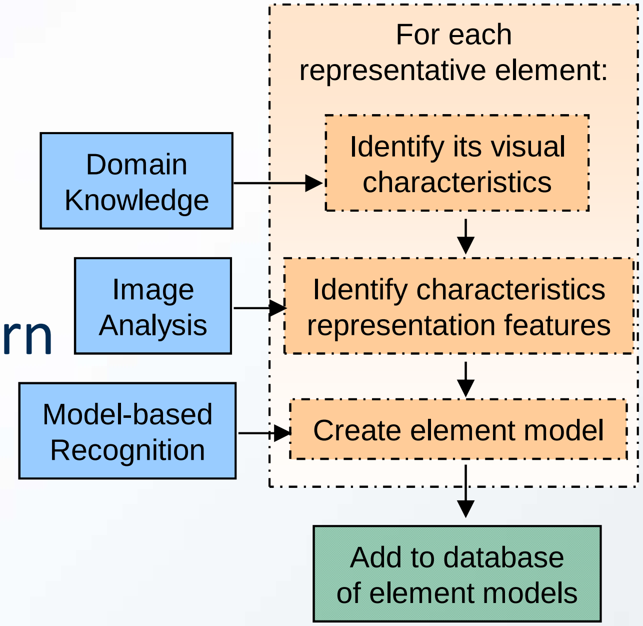
- Process of making a VPR model
  - Identify the distinctive characteristics
    - Characteristics of objects with a distinctive texture/shape signal pattern
  - Find/make the most suitable tool for recognizing each feature from
    - Images/Videos
    - Spatial geometry, and other sources
  - Tools/Features + relative topology bundled as object (VPR model) in a repository of VPR models



Results – Columns Detection

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- 89.1% precision (TP/TP+FP)
- 79.1% recall (TP/TP+TN)
- 320x240, 25 fps on a netbook

As-Built Geometry

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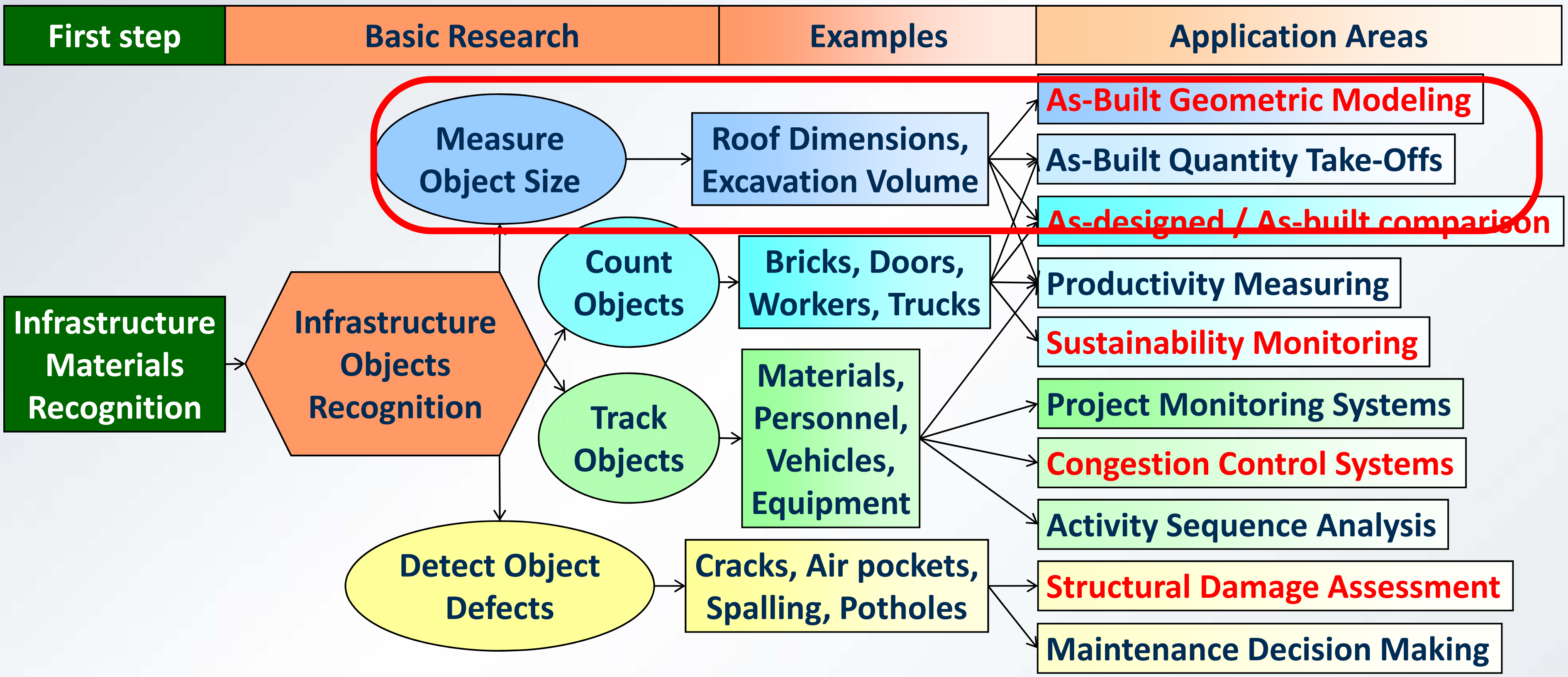
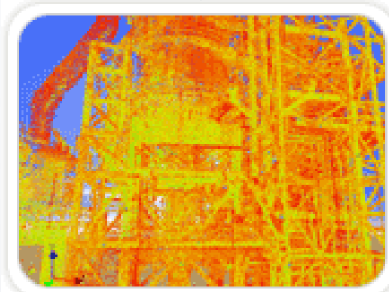
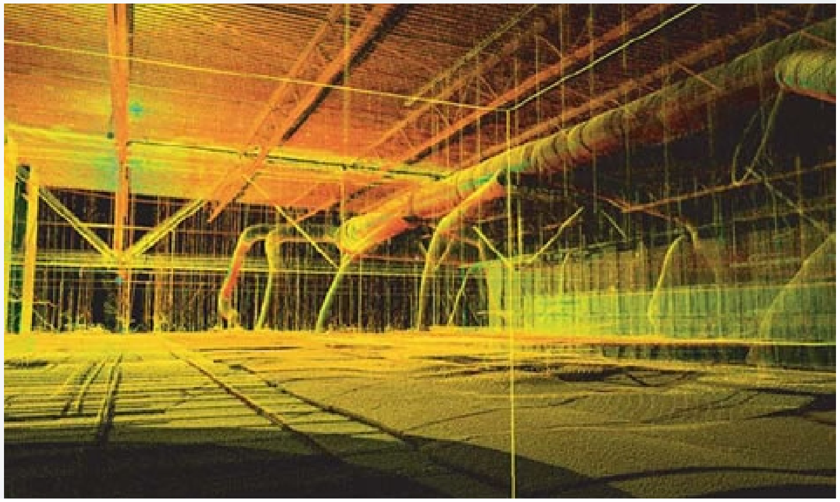


Real World Infrastructure to 3D Points

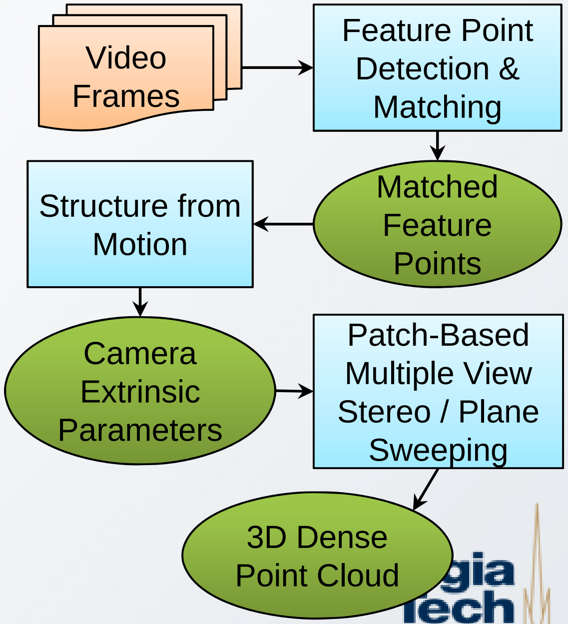
- Measuring object size needs 3D data
- Getting adequate/accurate 3D data is costly
  - Device costs (i.e. laser scanner)
  - Labor costs (data collection + post processing man-hours)
  - Result: Small/medium sized on-going and completed projects cannot afford it
    - Let alone getting 3D data frequently, throughout the construction phase





Short-Range, Mobile Videogrammetry

- Mobile camera set for real-time scanning
  - Often augmented with 3D range sensor
- Cost
  - Cameras vs. laser scanner
  - Automatic, no manual post-processing
- Time
  - View the results (3D points) while scanning, not days later
- Quality
  - Interactive, allows for correction of errors, occlusions, etc. immediately



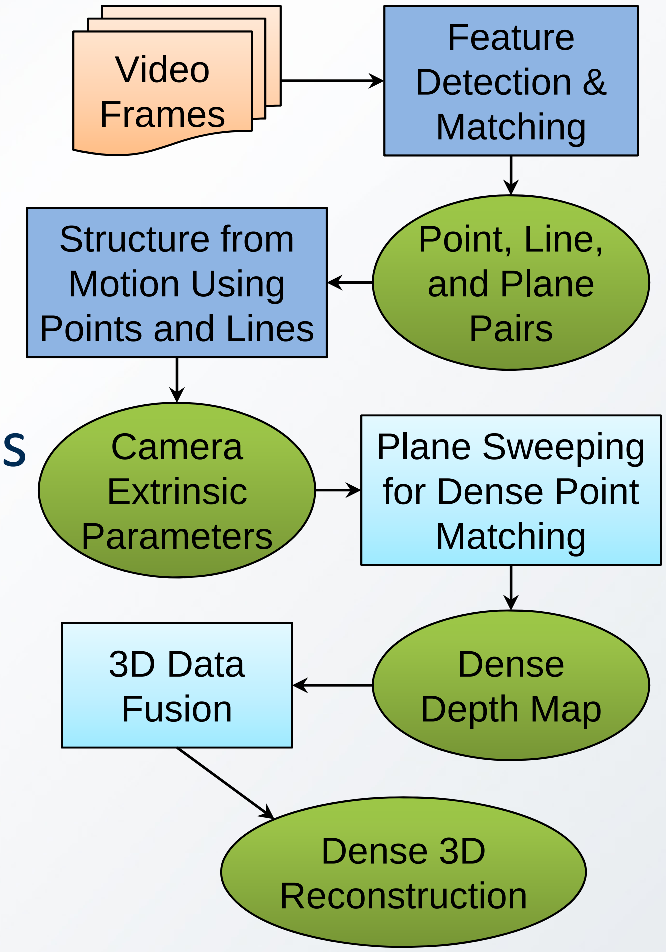
Short-Range, Mobile Videogrammetry

- Limitation: Low accuracy for long-range applications with poorly textured surfaces
- Research question: How to achieve an acceptable accuracy in this case?
- Objective: Reduce measurement error to standard engineering error rate (<7cm) @ a range of 20m or more
- Assumptions
  - Hardware: mobile, 2-camera set
  - Fixed variables: relative positions, focal length, zoom, lens aberrations

Long-Range, Mobile Videogrammetry

Grant #0904109

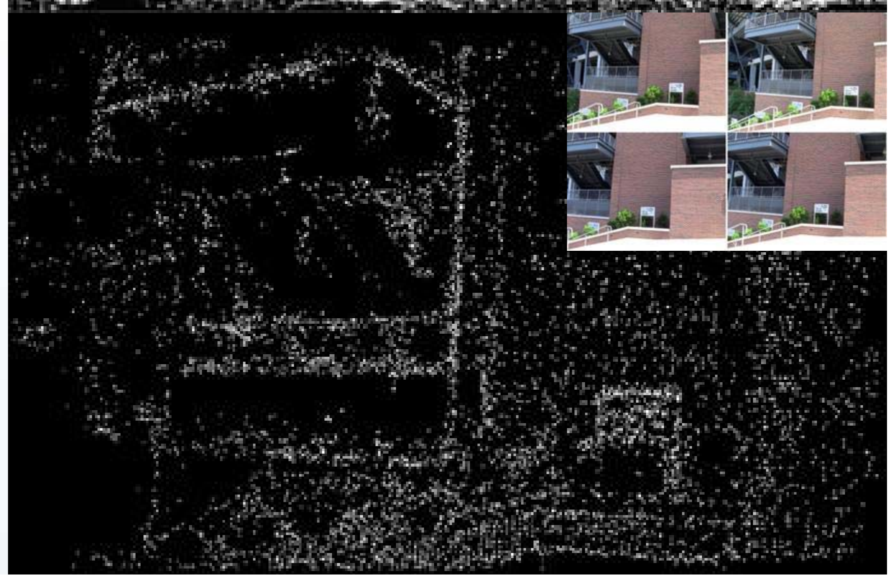
- Hypothesis: Desired accuracy can be achieved if, in addition to points, lines and planes are also used
- For each frame set
  - Detect point, line, and plane features
  - Match lines using SIFT-like descriptors
- Structure from motion
  - Combine data from all forms of features for more reliable estimations



Results

Grant #0904109

- Avg. error = 0.47 cm
- Std. dev. = 2.49 cm
- 95% conf. interval = 4.9 cm
  - Compared against manual tape measurements
- Range = 25 m distance from object



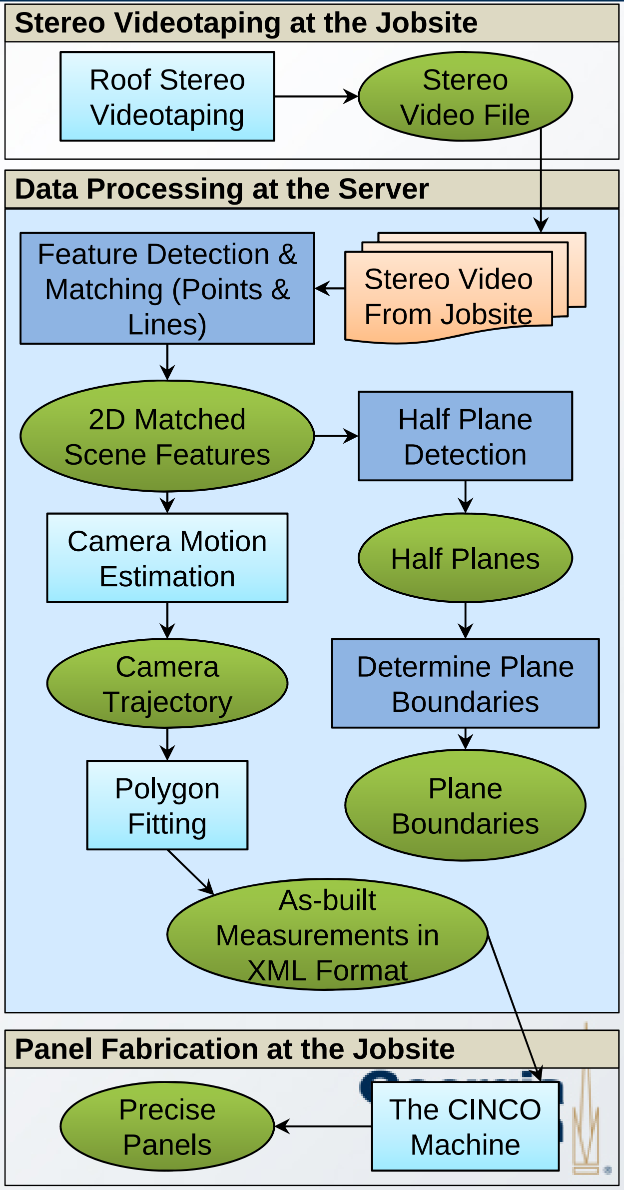
Spinoff: Roof Surveying

- Currently done with tapes or total stations, labor intensive
  - Measurements used for digital fabrication
- Video measuring could reduce costs

Videogrammetric Roof Surveying

- Using different forms of features
  - Points, lines, and planes
  - Line segment grouping
- Line matching using descriptors
- Detect half planes using homography
  - Represent roof planes
- Identify roof planes from half planes
  - Region growing to cover entire planes

→



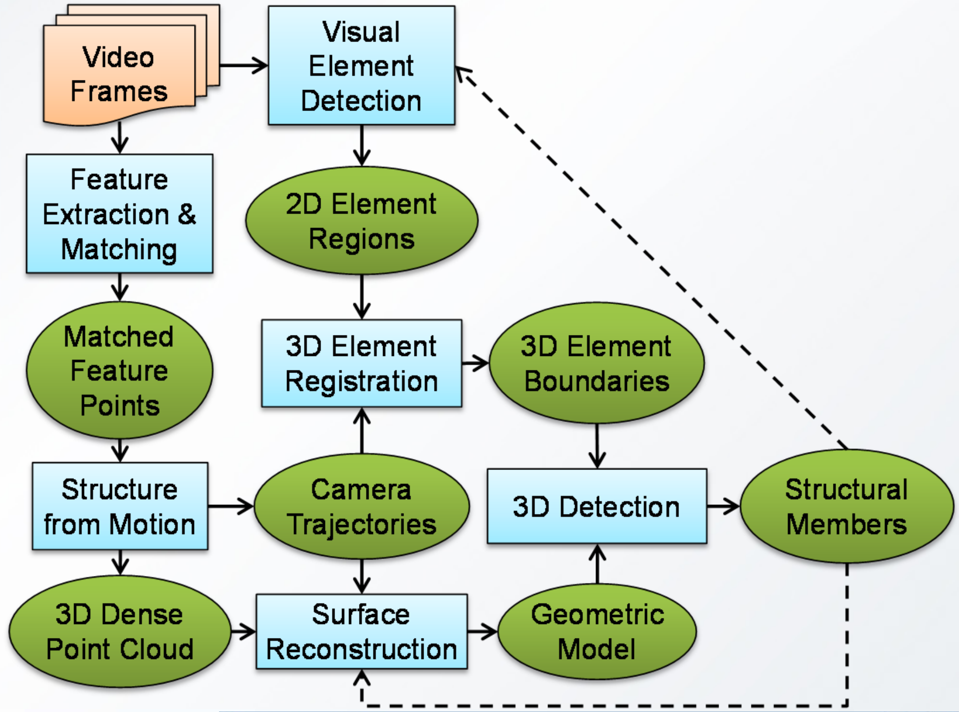
Results

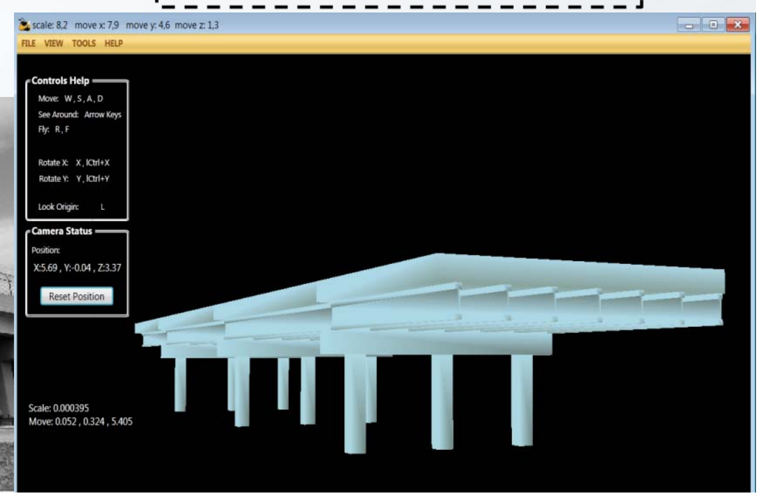
- Ground truth = total station measurements
- Range = 15 m from roof
- Avg. error = 0.9 cm
- Std. dev. = 0.34 cm
- 95% conf. int. = 1.57 cm
  - Target to reduce to 1 cm with global optimization
- Patents, tech transfer, commercialization
  - GRA, NSF I-Corps

Direct Approach: Reciprocal R&R

Grant #1031329
Co-PI: P. Vela

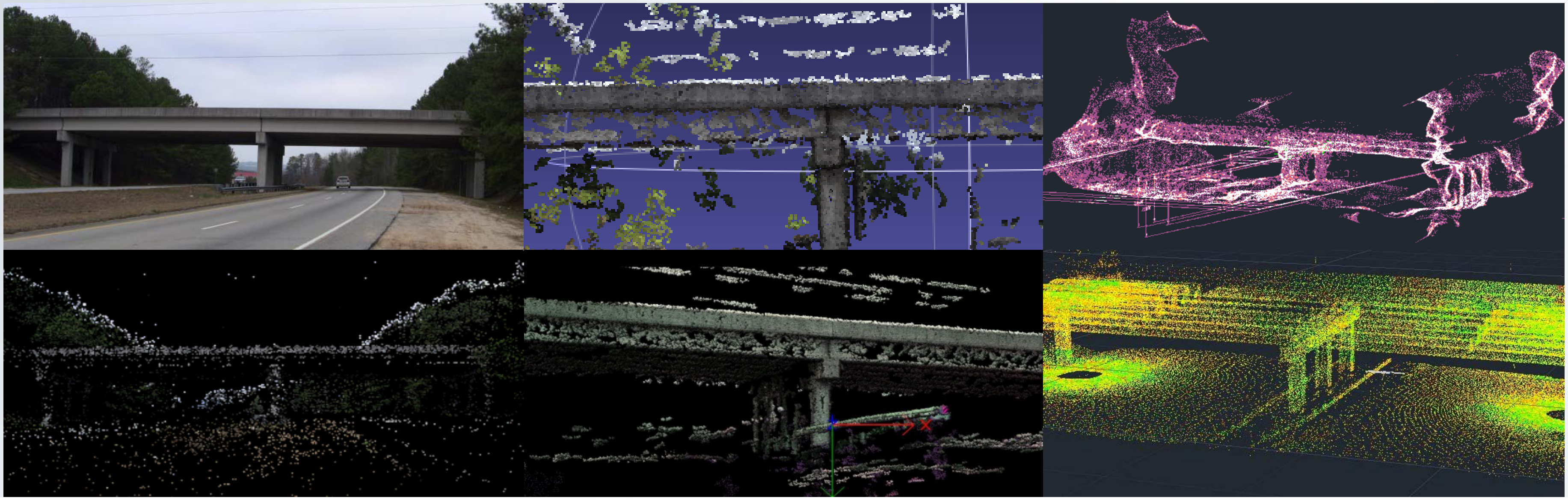
- First attempt to get infrastructure geometric model from single camera, no human input
  - RC Bridges chosen as simple, first examples
  - Compensate lack of 2nd camera with recognition





Results at 25m, Camera Res.=2MP

Grant
#1031329
Co-PI: P. Vela



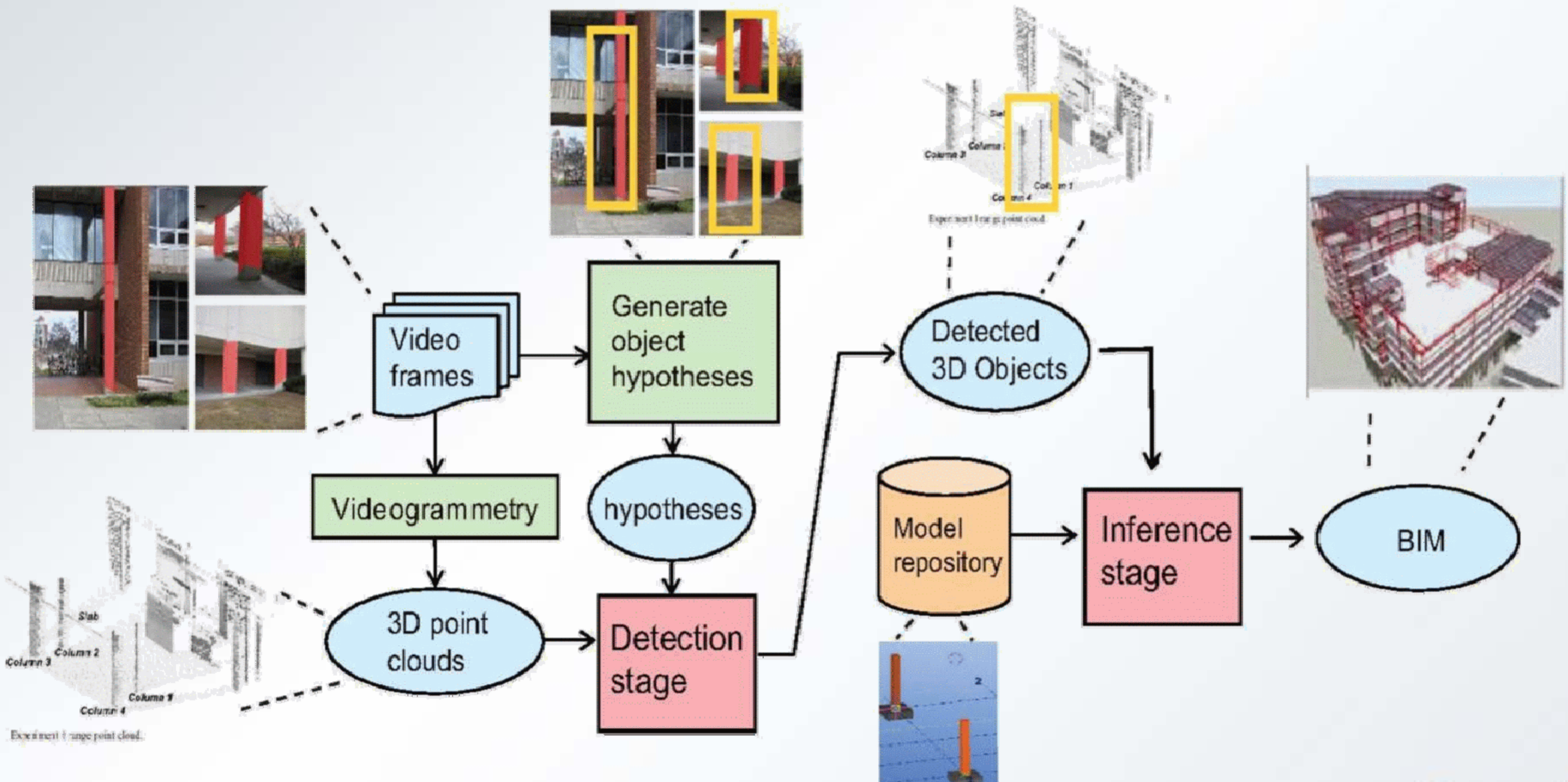
Method	Error (cm)	Completeness (%)	Density (pt/m^2)	Time (hr)	Cost ($)
Photogrammetry - Bundler+PMVS	7.2	73	8,310	6.0	1,100
Photogrammetry - PhotoFly	13.8	62	7,620	5.0	1,100
Photogrammetry - PhotoSynth	11.4	27	3,510	1.1	1,000
Videogrammetry - Canon Vixia	**6.6**	**79**	**8,540**	**3.2**	**1,075**
Videogrammetry - Point Grey	6.3	78	8,350	3.2	2,575
Laser Scanning - Leica C10	0.5	98	15,000	7.0	100,140 (rent=4,000)

Coordinating Efforts

Grant
BIMAutoGen

EUROPEAN
COMMISSION

- Consortium established in 2008 to formalize the as-built modeling process (video to BIM), coordinate efforts



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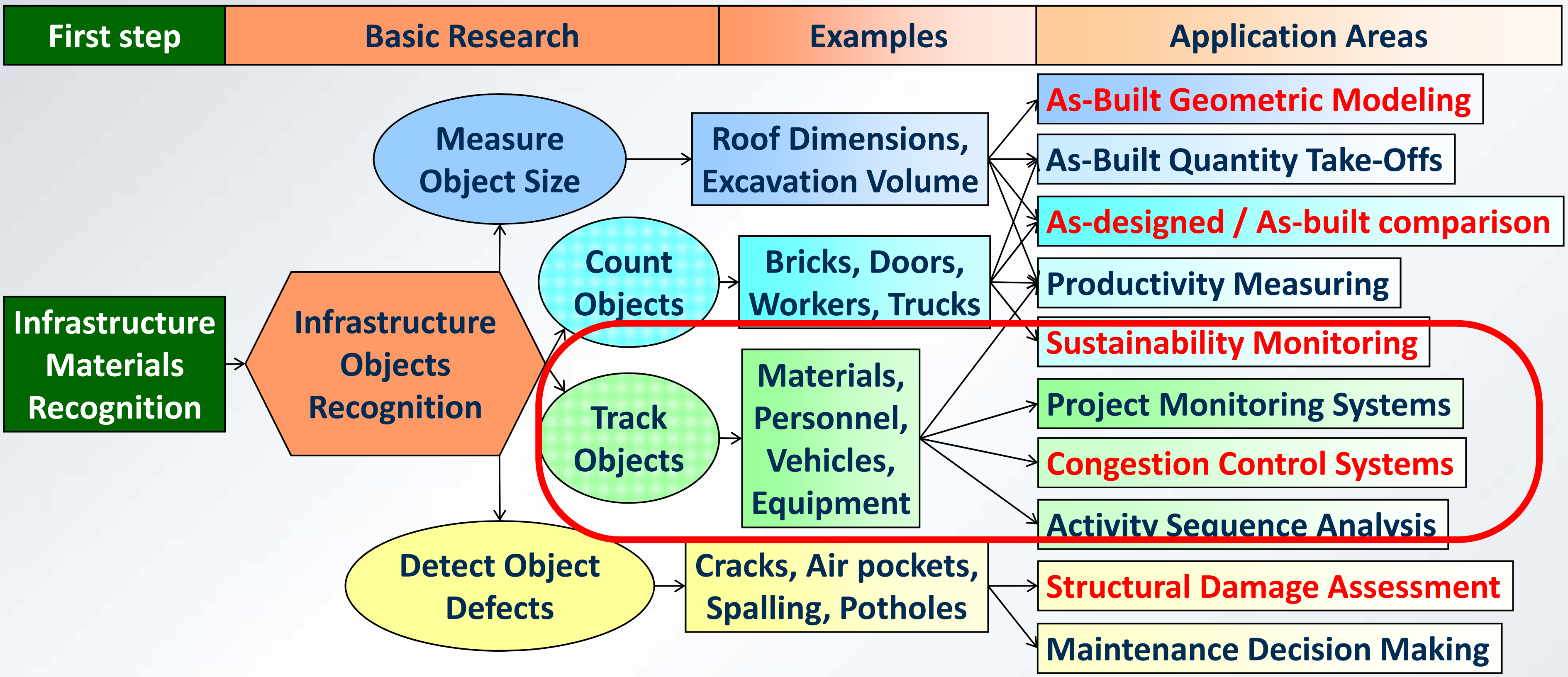
Vision Tracking

CAREER Award #0948415



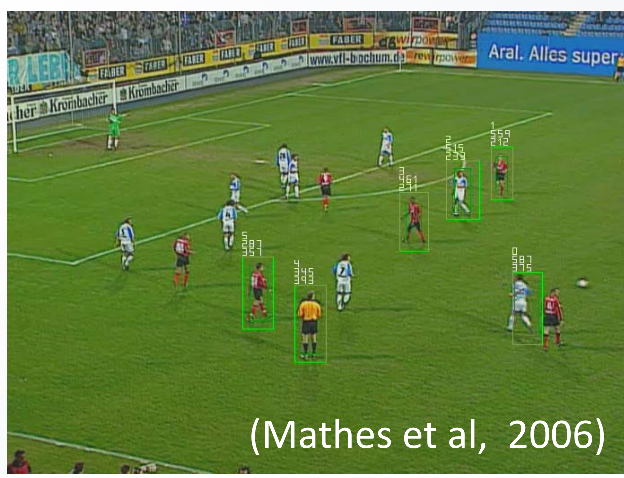
State of Practice

- Spatial monitoring of resources is possible today with radio frequency technologies
  - GPS, RFID, UWB, ZigBee, etc.

- Excellent for identification/ tracking of certain material and equipment types
  - Best solution for many projects
  - Poor solution when scaling up to large-scale, congested sites
    - Inefficient to tag 1000's of materials, 100's of equipment/personnel (high IT overhead)
    - Privacy issues (workers peeling off the tag)

State of Knowledge

- Vision Tracking
  - Ever wondered how the mileage run in a soccer game is measured?
- Benefits
  - No need for in-place sensors (tags)
  - Vast size of traceable area
  - Works with on-site construction cameras
- Methods
  - Contour-based
  - Kernel-based
  - Point-based



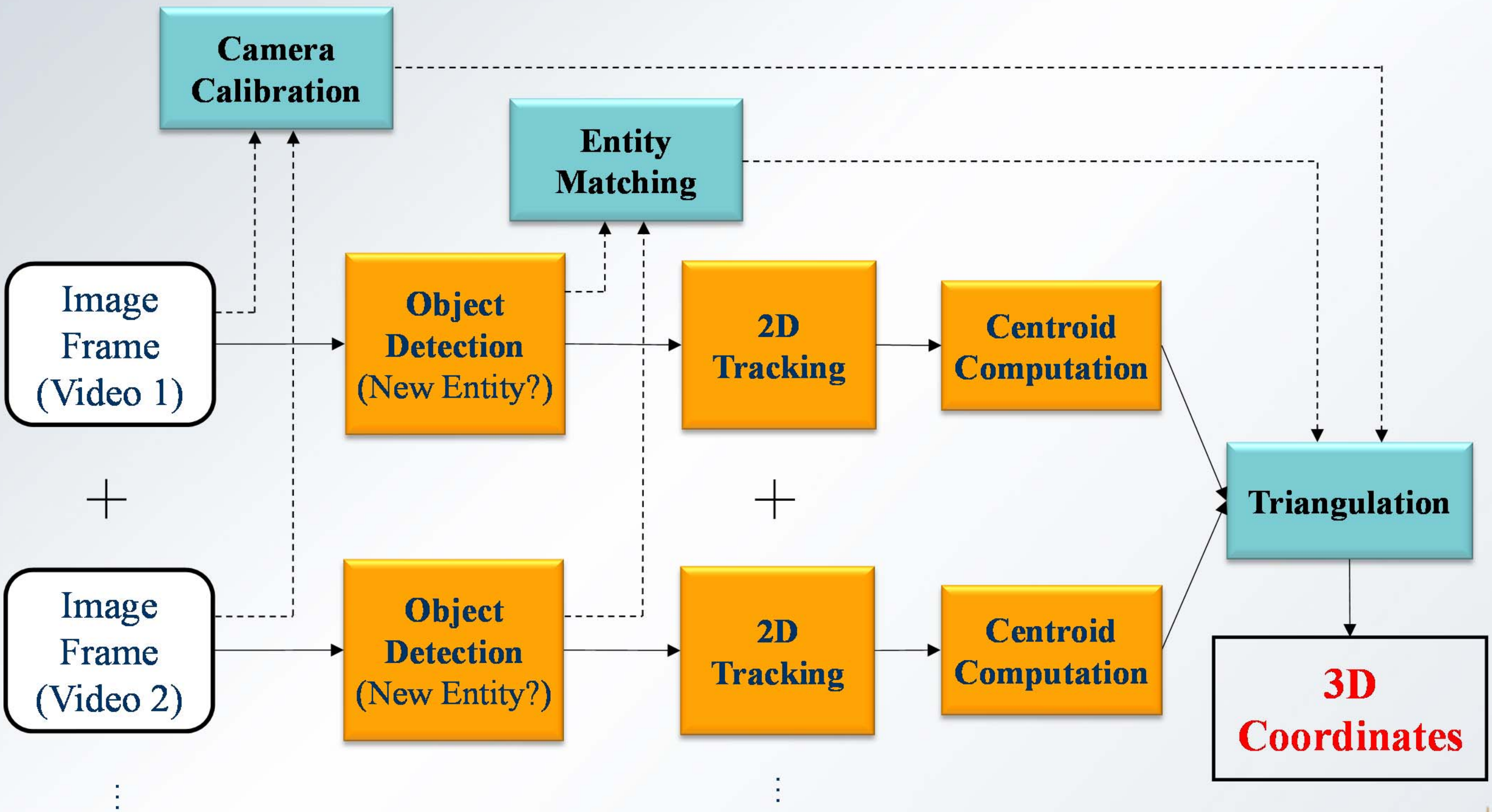
(Mathes et al, 2006)

Objectives

- Limitations
  - Need someone to mark interesting objects entering the view, very impractical
    - Research question: How to automate this marking?
    - Objective: Automate the recognition of construction resources for tracking initialization
  - Tracking happens in pixel coordinates (2D, not useful), instead of Euclidean coordinates (3D)
    - Research question: How to add the 3rd dimension?
    - Objective: Match objects across views, triangulate their 2D coordinates

Proposed Solution

Grant #0625643



Equipment & Worker Recognition

Grant #0625643

- Three types of image features: Motion, Shape, Color

Input Frame → Background Subtraction (Motion) → Moving object → Histogram of Oriented Gradients (Shape) → People-shaped object → Color Histogram (Color) → Worker

Input Frame → Background Subtraction (Motion) → Moving object → Haar-like features (Shape) → Equipment-shaped object → Eigen-images (Color) → Construction Equipment

Results – Worker Recognition

Grant #0625643

- Recognition of Workers (people wearing safety vests)

- Precision: 97.5%
- Workers detected within max. 0.57 seconds after they enter the scene

Results – Equipment Recognition

Grant #0625643

- 99.6% recall, 100% precision
- Occlusion: re-recognize when occlusion disappears

- Making turns: appropriate view shift

Blue = tracking only
Red = tracking + recognition

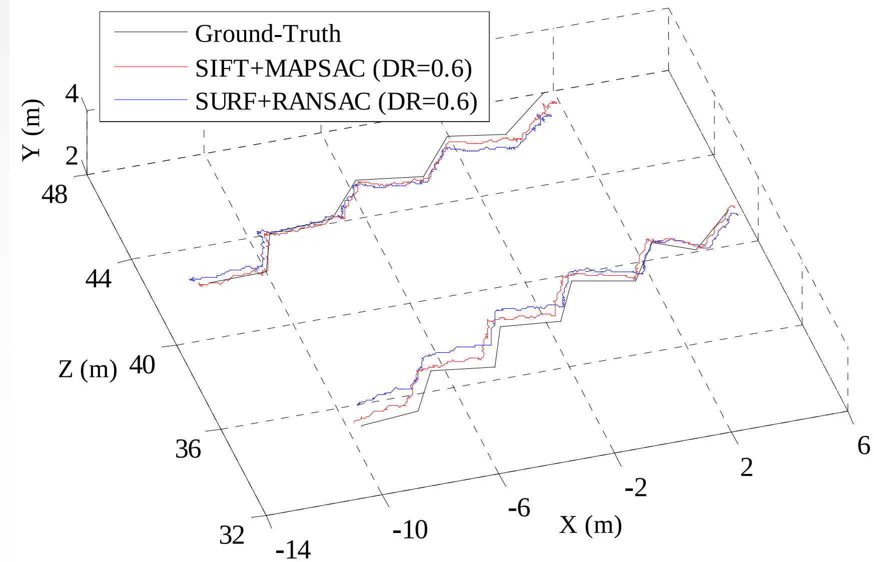
Results – 3D Tracking

Grant #0625643

Worker

Steel Plate

Left Right



Tracking a worker (Baseline=8.3m)

- Measured Errors
  - Distance between tracked points and ground-truth trajectory

Object Type	Steel plate	Van	Worker
Mean	0.18 m	0.28 m	0.43 m
Std. Dev.	0.13 m	0.19 m	0.31 m
Max. w/ 95% confidence	0.43 m	0.66 m	0.64 m

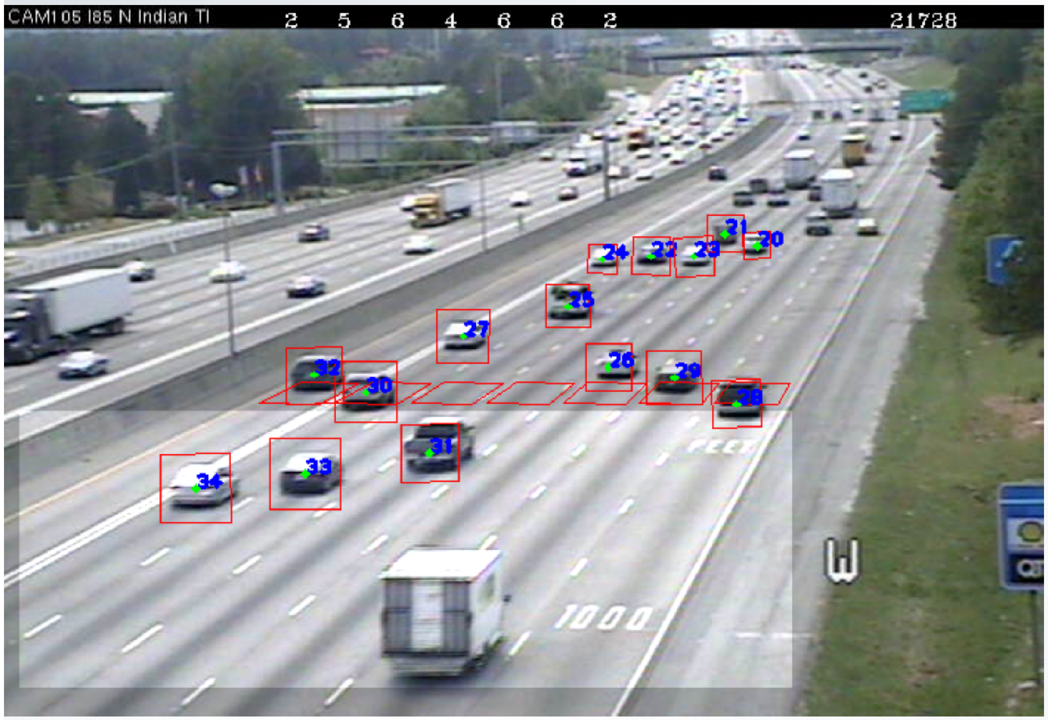
IREE: Large scale validation

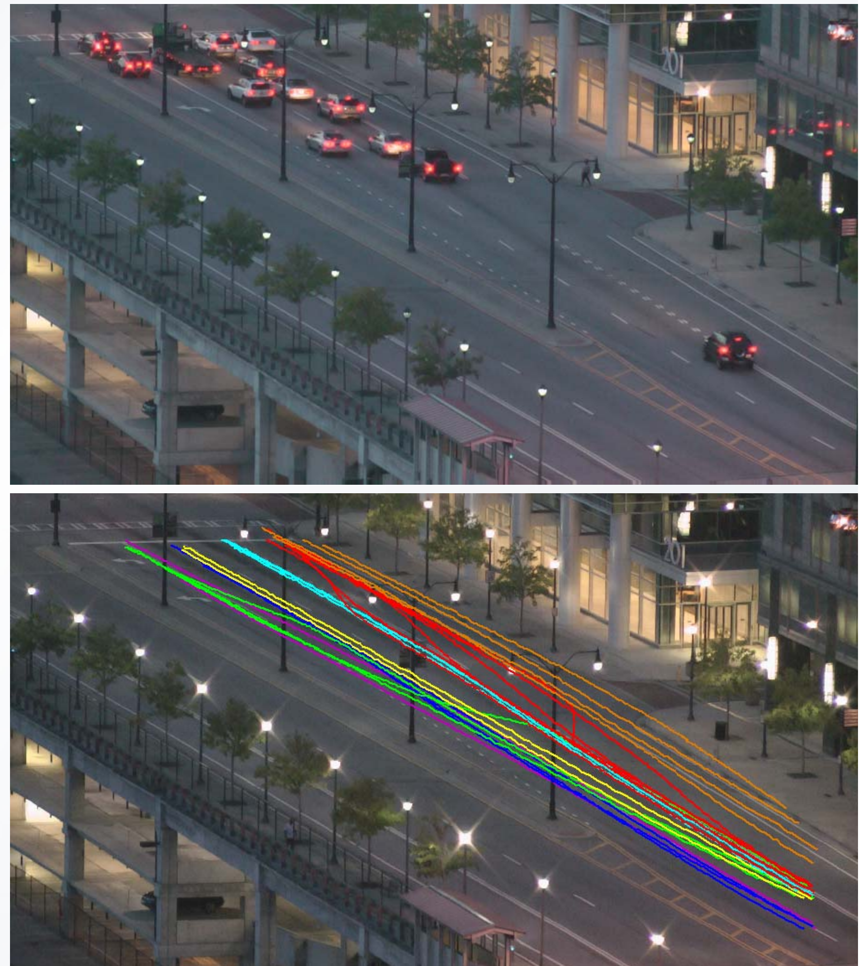
Grant #0738417

- 3 US + 2 GR students in Greece for 4 months
  - Egnatia Odos, Aposelemis Dam, Thessaloniki Metro, etc.

Spinoff: Traffic flow monitoring

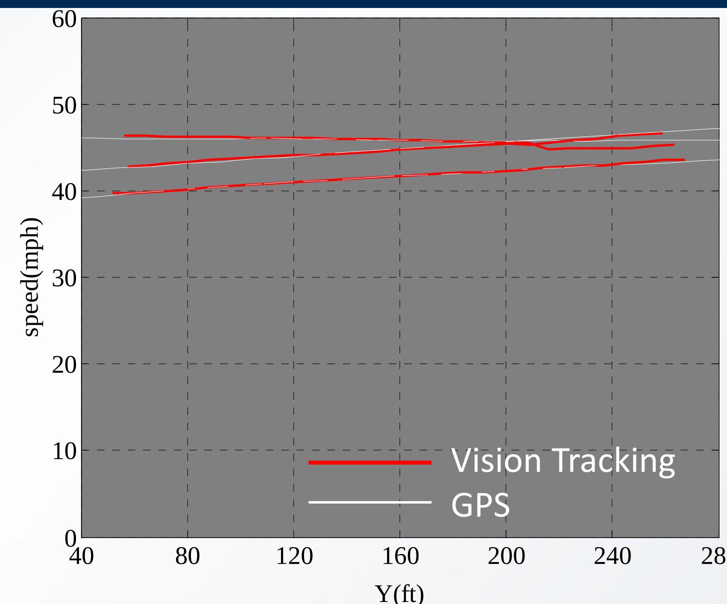
- Traffic flows in a much more structured way
  - Easier problem to tackle

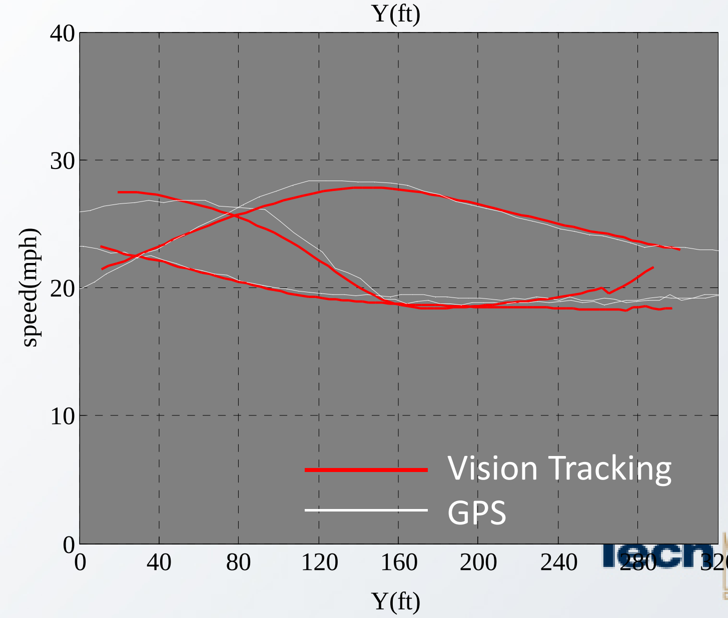




Spinoff: Traffic flow monitoring

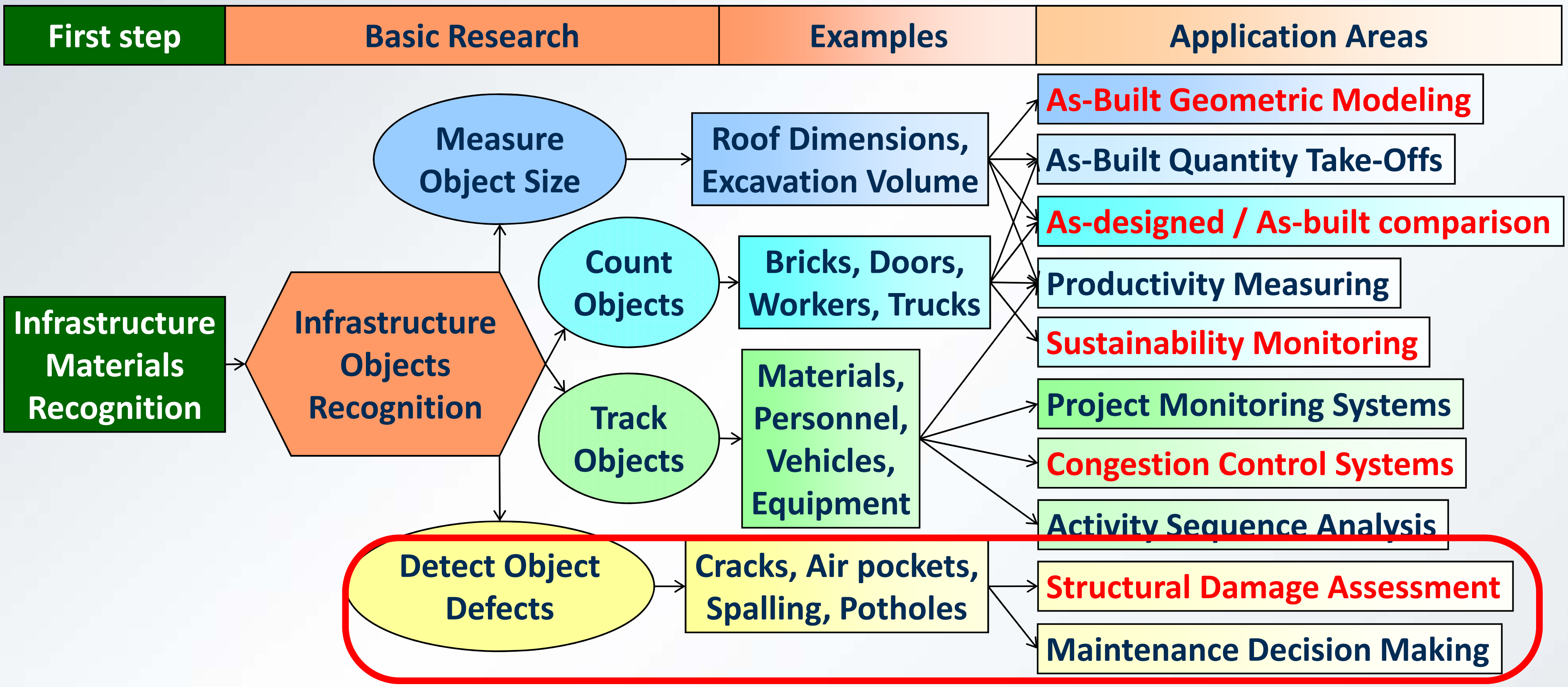
- Camera Calibration: coordinate transformation (image → road)
- Trajectory and Speed Calculation





Damage and Defects Assessment

CAREER Award #0948415



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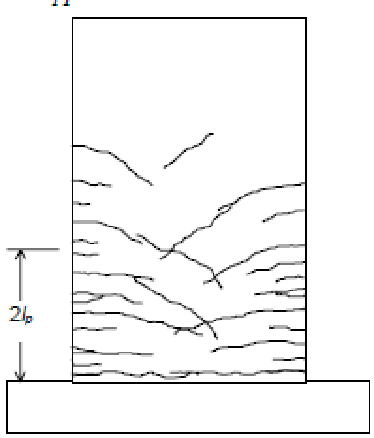
State of Practice

- FEMA 306 (rapid)
- ATC-20 (rough)
- FEM (detailed)

Severity	Description of Damage
Insignificant $\lambda_K = 0.8$ $\lambda_Q = 1.0$ $\lambda_D = 1.0$	*Criteria:* • No crack widths exceed 3/16 in., and • No shear cracks exceed 1/8 in., and • No significant spalling or vertical cracking *Typical Appearance:*



Note: l_p *is length of plastic hinge. See Section 5.3.3*

Damage Level	Performance Level	Qualitative Performance Description	Quantitative Performance Description
I	Cracking	Onset of hairline cracks	Barely visible residual cracks
II	Yielding	Theoretical first yield of longitudinal reinforcement	Residual crack width ~ 0.008in (0.2 mm)
III	Initiation of Local Mechanism	Initiation of inelastic deformation. Onset of concrete spalling. Development of diagonal cracks.	Residual crack width 0.04in – 0.08in (1 – 2mm). Length of spalled region > 1/10 cross-section depth.
IV	Full Development of Local Mechanism	Wide crack widths/spalling over full local mechanism region.	Residual crack width > 0.08in. (2mm). Diagonal cracks extend over 2/3 cross-section depth. Length of spalled region > ½ cross-section depth.
V	Strength Degradation	Buckling of main reinforcement. Rupture of transverse reinforcement. Crushing of core concrete.	Lateral capacity below 85% of maximum. Section depth expands to > 5% of original member dimension.

Field Observations				Conclusions	
Pronounced Horizontal Cracks	Pronounced Diagonal Cracks	Incipient Concrete Curshing/ Spalling	Long. Bar Buckling	Damage Level	Possible Failure Type
No	Yes	No	No	III	Shear
No or Yes	Yes	Yes	No or Yes	IV or V	Shear
Yes	No	No	No	II or III	Flexure
Yes	No	Yes	No	IV	Flexure
Yes	No	Yes	Yes	V	Flexure

Problem Statement & Objectives

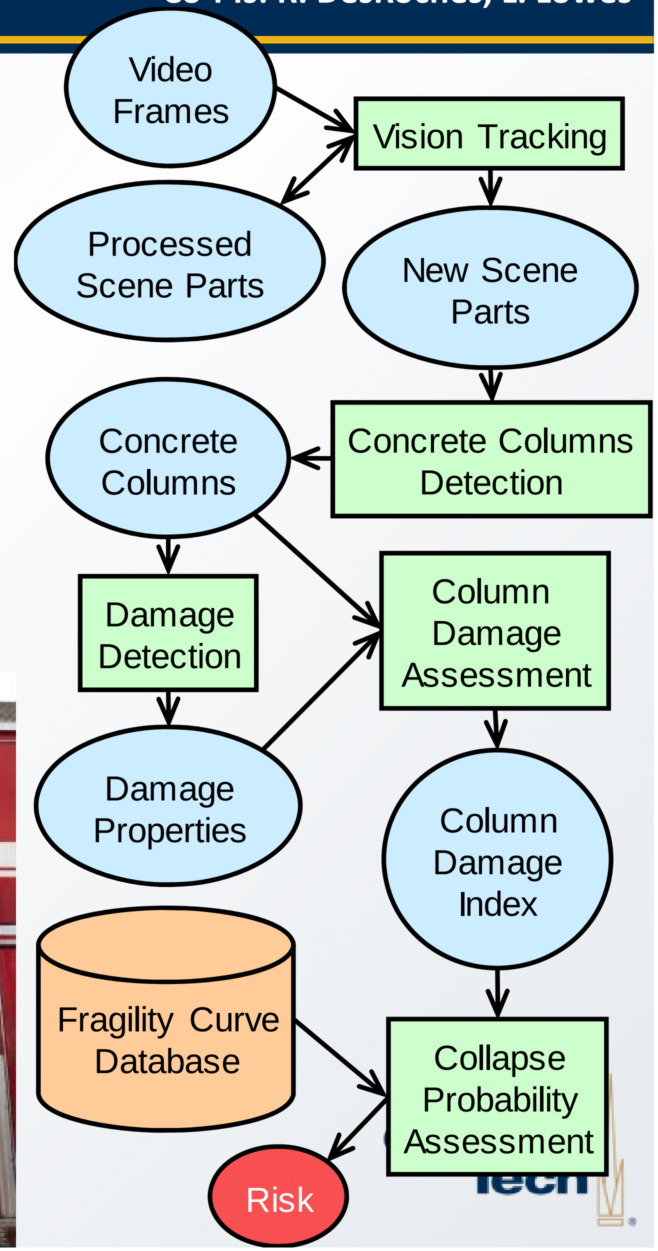
- Problem
  - Earthquakes create huge inspection demand within seconds
    - Takes weeks to months to assess all structures
    - In the mean time
      - Emergency responders risk their lives entering unsafe buildings (FEMA codes)
      - People stay out of their homes/businesses waiting for the assessment (ATC codes, detailed FEM)
- Objective
  - Shift the research focus from accuracy to speed
    - Get useful measurements automatically

Proposed Solution

Grant #1000700

Co-PIs: R. DesRoches, L. Lowes

- Hardhat camera broadcasts video
- Columns and damage on them is recognized
- Pixel dimensions correlated to get relative spatial measurements
- Measurements used to estimate component load bearing capacity index
- Indices + columns arrangement used to estimate probability of collapse

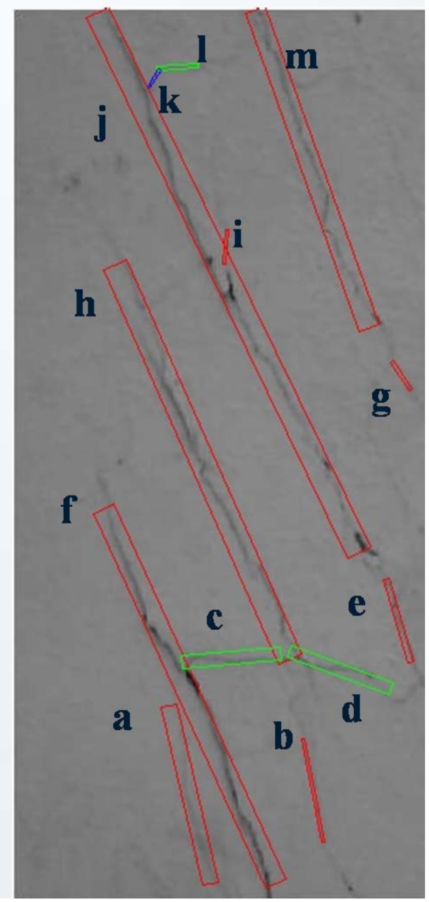


Results – Cracks, Spalling

Grant #1000700
Co-PIs: R. DesRoches, L. Lowes

- Cracks measurement error:
- Exposed reinforcement detection performance
  - Precision: 87.2%, Recall: 87.4%

	|Δ| - Orientation	|Δ| - L / W*	|Δ| - Max W / W*
Average	3.29°	2.21%	0.35%
Std	2.70°	2.90%	0.49%



Conclusion

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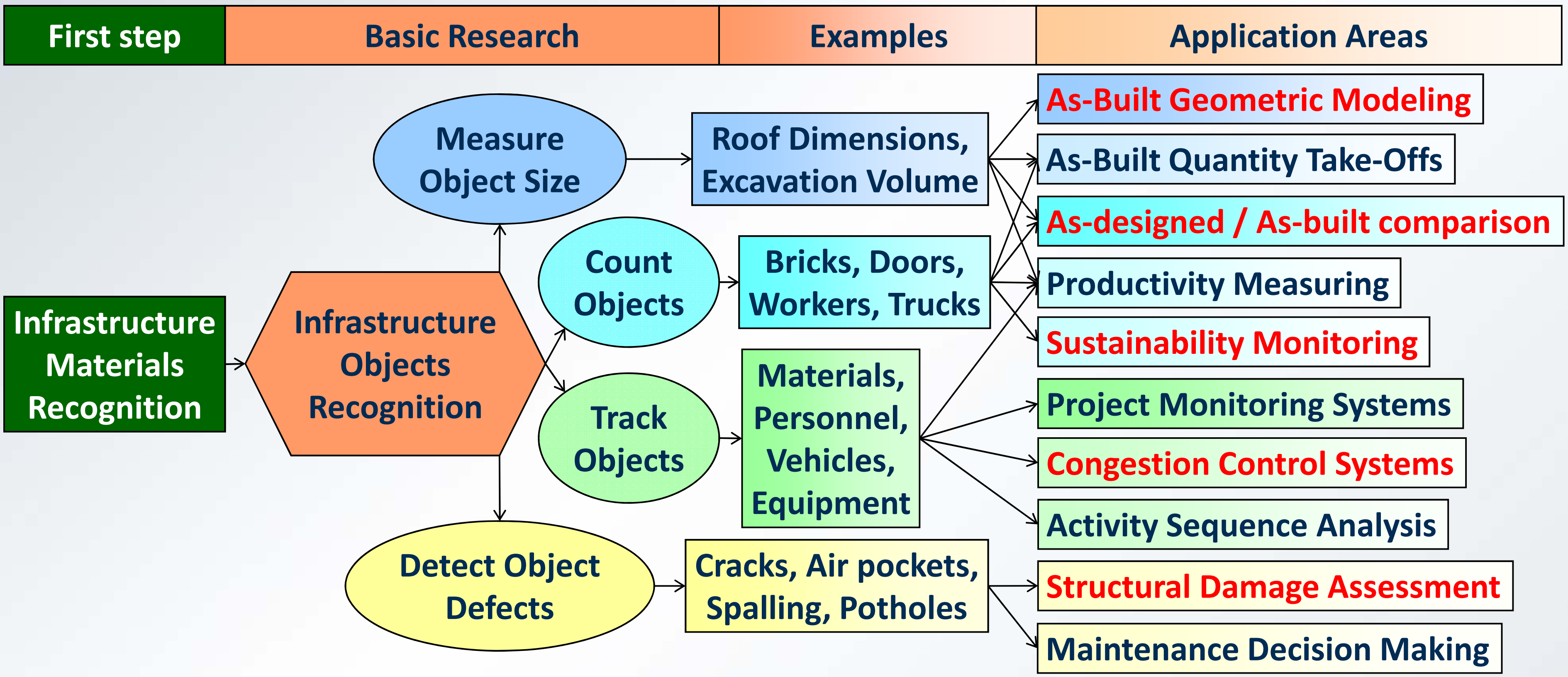

Thank you!

Questions?

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